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Simulation of a 13-Level Inverter with Facts Capability for Distributed Energy Systems

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ABSTRACT

*In this paper, flexible ac transmission capable wind energy system is shown. Similar to Conventional WEI, between the wind turbine and the grid an inverter is connected which can regulate both active as well as reactive power transferred to the grid. In this inverter proposed here D-STACOM is provided to control the power factor of the feeder lines. This inverter system proposed here can eliminate the use of capacitor banks and Facts devices to control the power factor of the distribution line for small and medium wind turbine generator application. This paper is presented as a view to enhance the use of renewable energy sources in the distribution system. With the help of this proposed system utilities and consumers can also act as supplier of energy. Also this FACTS capable of new type converters will reduce the cost of renewable energy application. To meet the desired IEEE standards for a single phase system such as total harmonic Distortion (THD), efficiency and cost of system a modular multilevel inverter is used here. The control strategy in this to regulate the active and reactive power with the help of power angle and modulation index. Here the proposed inverter system should transfer the active power to the grid while maintaining the PF of the power lines constant irrespective of active power coming from wind turbine. The control strategy is to regulate the active and reactive power with the help of power angle and modulation index. Here the proposed inverter system should transfer the active power to the grid while maintaining the PF of the power lines constant irrespective of active power coming from wind turbine. A 13-level inverter have been simulated in MATLAB/Simulink. The simulation result is validated, by taking the prototype scaled model of proposed inverter system.***

KEYWORDS: *Modular multilevel converter (MMC), Multilevel Inverter (MLI),* Wind Energy Inverter (WEI)

I. INTRODUCTION

In wind turbine application power electronics application has been increased .the power electronics devices converts the nonconventional form of energy to the suitable voltage and frequency energy for grid. In wind turbine application, generator and grid are connected with the help of back-to-back converters. In wind turbine applicationAsynchronous ac power is first converted to dc power with the help of rectifier which has maximum power point tracker (MPPT).this dc power is then converted to ac power with desired frequency using Inverters and transformers. Asynchronous power Wind energy is important in distributed energy supply system. As the number of wind turbines increases the problem of harmonics or power factor also increases. As low the PF increases the power loss and voltage regulation. Therefore to reduce the power loss and voltage regulation high PF is needed. This can be achieved by supplying reactive power need the load with the help of capacitors banks and other sources. Generally power factor should be kept nearer to 1 which will reduce current and power loss. As this capacitor bank increases the cost ofthe system. Therefore Distributed static synchronous capacitor (D-STATCOM) re used now a days. The D-STATCOM is connected in parallel with the power system which will act as a source or sink of reactive power to increase the power factor. Traditional STATCOM are costly and hence uneconomical for small-to-medium size single phase wind turbine application. Therefore cost effective and IEEE standard capable system is needed. In this proposed inverter system with D-STATCOM can regulate reactive power and connected between wind turbine and grid. In this proposed inverter system with D-STATCOM can regulate reactive power and connected between

wind turbine and grid. This proposed inverter converts the dc power from dc link to ac power at the same time by injecting reactive power fix the PF of the system. Here the inverter and D-STATCOM are combined here. Here inverter

with D-STACOM acts as inverter when sufficient wind is available and act as D-STATCOM when wind is not available. Here the active power is controlled by adjusting the power angle δ and reactive angle is controlled by adjusting modulation index m.

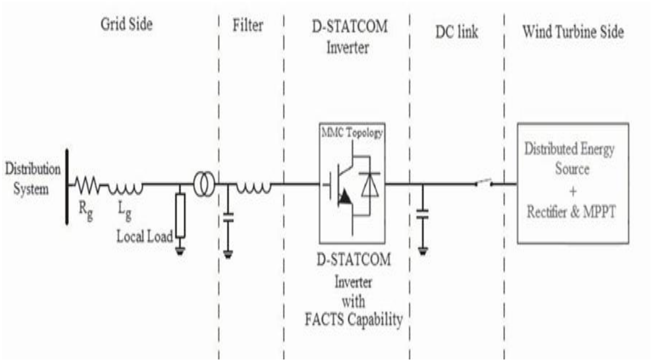

Figure 1 Configuration of Proposed Inverter System with FACTS Capability

In this multilevel converter technology is used. Among various multilevel converter methods, the cascaded H- bridge converter is widely used because of ease of obtaining high number of levels to connect STATCOM directly to medium voltage grids. This inverter is connected between wind turbine and grid, but this suffers from the drawback of current fluctuations which are not meeting IEEE standards. To eliminate the use of separate capacitor bank or STATCOM conventional inverters are replaced with WEI utilizing MMC Topology to fix the power factor of the grid. The proposed method here meets with the IEEE standards and can control the PF of grid irrespective of wind speed. Fig 1 shows the complete grid connection of proposed method .here wind turbine and dc link of the inverter is connected through inverter with MPPT then its output is connected to utility grid through filter and distribution transformer.

II. Multiple Modular Inverter

The MMC application is increasing now a days. It consists of several half bridge sub modules per phase. An n-level single phase inverter has 2(n-1) sub module and 2 buffer inductors. Each sub module has two semiconductor switches to operate in complementary mode and a capacitor. This method is ideal for medium to high voltage wind turbine application. It has the advantage that it needs only one dc source but it needs a large capacitor which increases the cost. But this cost is compensated by the elimination of snubber circuit. This method is modular in design, simple in voltage scaling and possibility of common dc bus. Fig 2. Shows single phase MMC with its sub module consisting of 2 power switches and a capacitor. Depending upon the switching states, the output voltage of each sub module (v_o) is either full capacitor voltage (v_c) or zero.

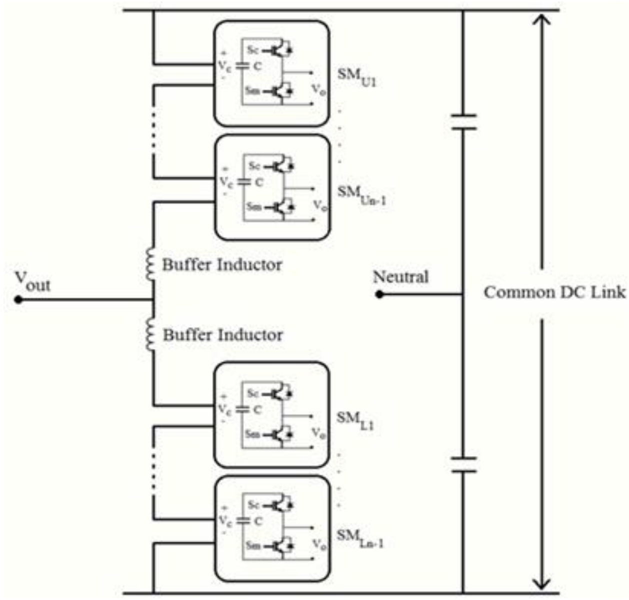

Figure 2 Single phase MMC Inverter structure

Mode	Sm	Sc	Vo
1	Off	On	Vc
2	On	Off	0

Table 1Failure free switching states for each SM of MMC topology

The buffer inductor are used to provide current control in each phase arm and to limit fault currents. The operation of MMC can be described by considering each sub module (SM) as a two poleswitch. If the status of i^{th} sub module (S_{ui}) in the upper arm is equal to unity then the i^{th} sub module output is equal to corresponding capacitor voltage, else it is zero. Similarly,Ifthe status of i^{th} sub module (S_{li}) in the lower arm is equal to unity then the i^{th} sub module output is equal to corresponding capacitor voltage, else it is zero. When the status of any sub module capacitor voltage, else it is zero. When the status of any sub module is equal to 1 then that sub module (SM) is on.Thus when the status of (S_{ui}) or (S_{li}) is 1 then i^{th} sub module in the upper and lower arm is on otherwise off. Therefore in MMC, the upper arm and lower arm voltages are:

$$v_{upper\ arm} = \sum_{i=1}^{n-1}(S_{ui}v_{ci}) + v_{11}(1)$$

$$v_{lower\ arm} = \sum_{i=1}^{n-1}(S_{li}v_{ci}) + v_{12} \quad (2)$$

Where v_{11} and v_{12} are the upper and lower arm buffer inductor voltages, n is number of voltage levels, and v_{Ci} is the i^{th} inductor voltages, n is number of voltage levels, and v_{Ci} is the i^{th} SMs capacitor voltages in upper and lower arm.A single-phase 13-level MMC inverter consists of 24 SMs which translates to 44 power switches, 24 capacitors, and two buffer inductors. The DC and AC voltages of the 13-level MMC are described by:

$$v_{DC} = v_{upper\ arm} + v_{lower\ arm}$$

$$= \sum_{i=1}^{12}(S_{ui}\,v_{ci}) + \sum_{i=1}^{12}(S_{li}\,v_{ci}) + (v_{11}+v_{12}) \quad (3)$$

$$v_{out} = \frac{v_{dc}}{2} - v_{upper\ arm} = -\frac{v_{dc}}{2} + v_{lower\ arm} \quad (4)$$

III. CONTROL STATEGY

It has three major function: 1. to control active and reactive power transferred to lines, 2. to keep capacitor voltages balanced, 3.to generate desired PWM signal.

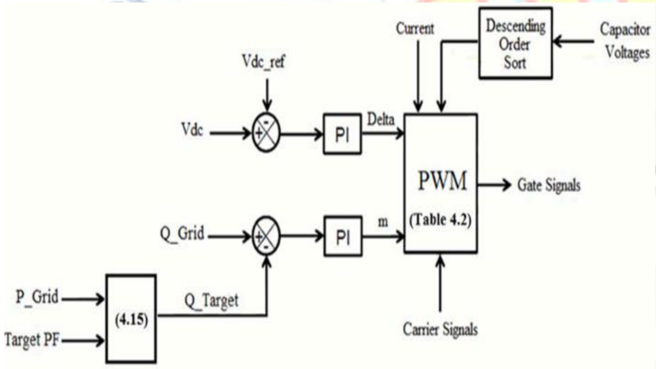

Figure 3 Schematic of proposed controller strategy

The proposed inverter should be able to transfer active power coming from the wind turbine at the same time provide reactive power compensation and power factor correction of feeder lines. The active and reactive power control of inverter should be fully independent, so that it can act as inverter while maintaining the PF of local grid (D-STATCOM options) when wind blows. Otherwise it acts as a D-STATCOM to regulate the PF of grid. This lead two mode operation 1).when wind is enough and the wind turbine is supplying the active then the device will act as an inverter as well D-STATCOM to transfer the active power from renewable energy source to the grid while maintaining the PF of grid and 2). When wind is not blowing and is blowing very slowly for active power generation then device act as a D-STATCOM which will act as a source of reactive power to control the PF of grid Thus it eliminates the need of costly capacitor banks. This device is capable of supplying max rated real or reactive power and it will always supply its total generated real power to grid. The maximum reactive power is depended on utility demand need.

The power flow between a STATCOM device and power line is-

$$P_s = -\frac{E_S E_L}{X}\sin\delta \quad (5)$$

$$Q_s = -\frac{E_S E_L\cos\delta - E_S^2}{X} \quad (6)$$

Where X is inductance of line between STATCOM and grid, E_S is RMS voltage of STATCOM and is suppose to be out of phase by an angle δ to the line voltage E_1 . By selecting proper voltage level of the inverter and the angle δ between the voltages of inverter and grid, we can control the active and reactive power transferred between inverter and grid. The inverter voltage is controlled with help of modulation index m and angle δ by adding delay to firing signal.

$$P_s = -\frac{mE_S E_L}{X}\sin \quad (7)$$

$$Q_s = -\frac{mE_S E_L\cos\delta - E_S^2}{X} \quad (8)$$

Here **"m"** is responsible for reactive power compensation control and the grid PF equal to target PF and δ is for active power control between grid and inverter. Some assumption has been taken for this this controller: 1) the load on the feeder line is assumed to be fixed for a small time with load does not change during a cycle of the grid frequency; 2) we can accurately modelled the feeder line as a constant P,Q load. Thus power produced by a wind turbine will distribute other power on the feeder line and does not add to it; and 3) although by changing **m** or **δ** has effect on both (7) and (8), it is supposed to be that a change in the modulation index will strongly affect Q, whereas change in delta will strongly affect P. thus any effect of small change in delta Q is ignored .Thus P and Q can be controlled independently. The relation between the target reactive power and the target PF

$$P_G = \left(\sqrt{P_G^2 + Q_T^2}\right) \times PF_T \quad (9)$$

Where P_G is active power on the grid, Q_T is the target reactive power, and PF_T is the target PF desired. So, Q_T can be calculated as

$$Q_T = \sqrt{\left(\frac{P_G}{PF_T^2}\right) - P_G^2} \quad (10)$$

From equation (9) and (10), set value of reactive power for the grid can be determined and compared with grid's actual reactive power. the controller system also performs the function of keeping the capacitor's voltage balanced. each region has a certain voltage range in the 13 operating region .

$$n_{upper\ arm} + n_{lower\ arm} = 12$$

Here $n_{upper\ arm}$ and $n_{lower\ arm}$ represents number of SMs that are on in the upper arm or lower arm.there are twelve upper and twelve lower SMs In an 13-level MMC inverter in which each SM has a capacitor. The MMC control suffers from the issue of voltage unbalanced among capacitors. Therefore for each half cycle SMs voltage are measured and sorted in descending order. When positive currents are flowing through switches then the capacitor is charging $n_{upper\ arm}$ and $n_{upper\ arm}$ and of the SMs in upper arm and lower arm which has lowest voltage is selected respectively. Therefore twelve capacitors which had lowest voltages are chosen to be charge. The unique concept in this paper is that here 13 level inverter is simulated with neural controller instead of conventional PI controller.

IV. SIMULATION AND PRACTICAL RESULTS

The design of a 13 level MMC inverter was carried out in MATLAB/Simulink. The simulation time is taken One second with the goal of assessing the system behavior in worst conditions. The target power factor is expected to be 0.9. The simulation diagram and result has been shown below:

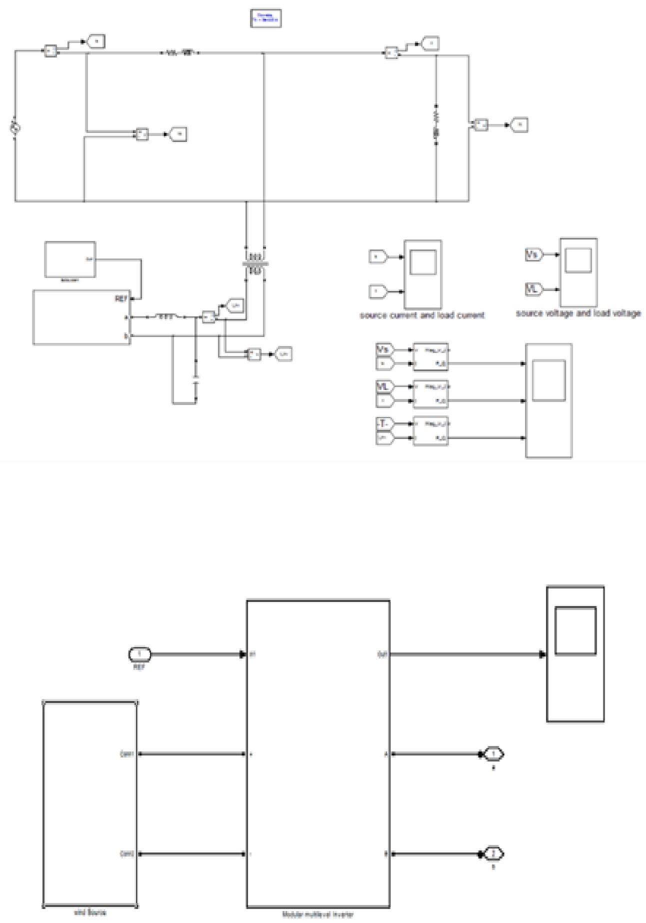

Figure 4 Wind Generator Connected To Local Grid

The 13 level consist of 6 upper arm sub module and 6 lower arm modules.

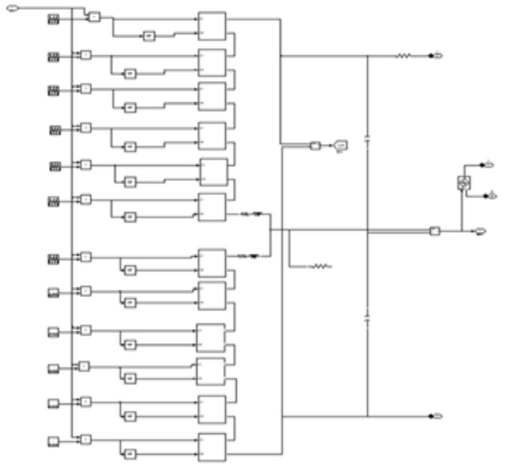

Figure 5 13 level inverter

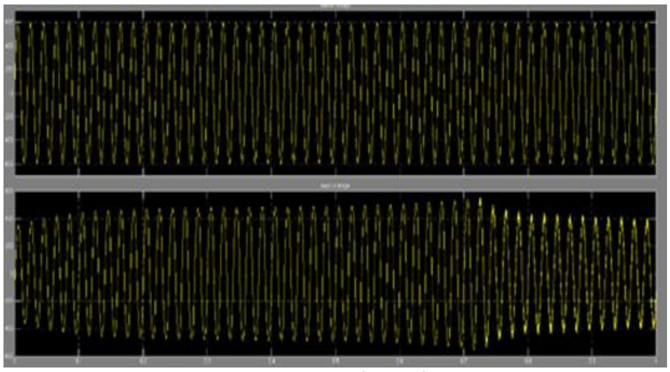

Figure 6 Source and Load current

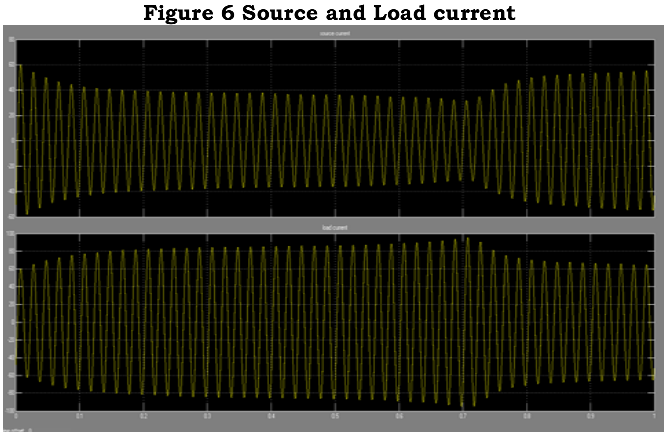

Figure 7 Source Voltage and Load voltage

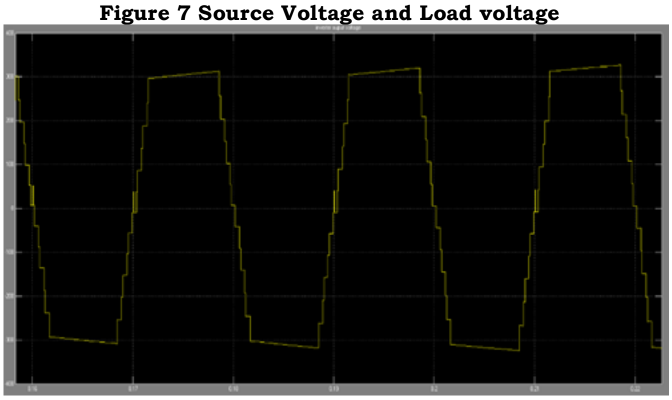

Figure 8 Inverter Output voltage

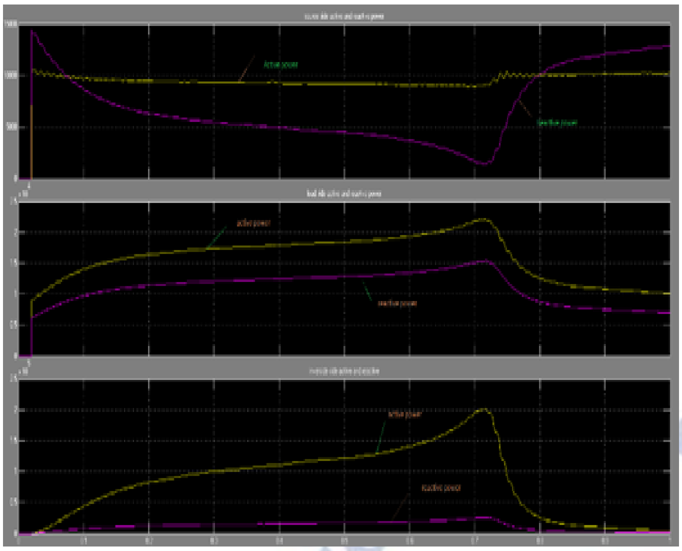

Figure 9 Active and Reactive power at Source, Load and Inverter side respectively

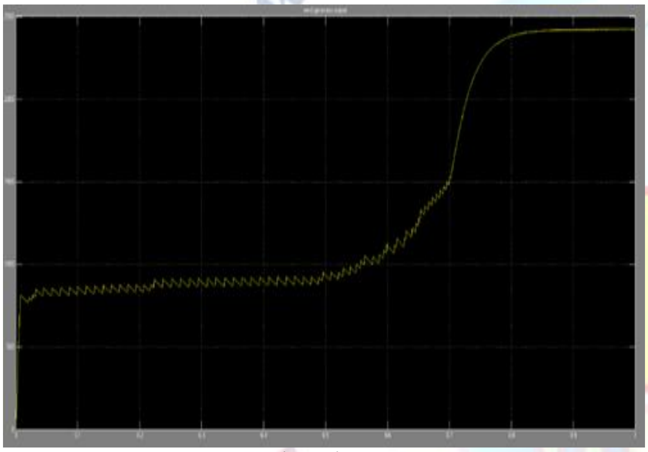

Figure 10 Wind Turbine Output Power

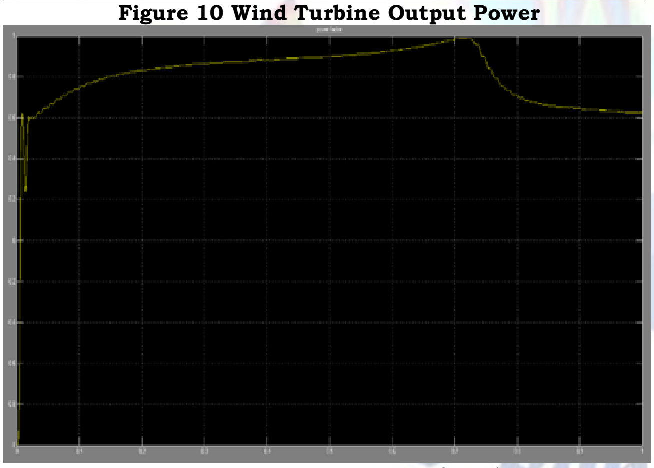

Figure 11 Power Factor of Grid

V. CONCLUSION

Here Flexible ac transmission capable wind energy system for small-to-medium wind installation is presented. The proposed system can transfer the active as well as reactive power between grid and source to regulate the PF of the grid thus eliminating the need of external any STATCOM. In this proposed method regard less of wind speed the PF of the system remains constant. With respect to the amount of compensation, the MMC inverter will have to get the target PF. Here 13 level Inverter is simulated in MATLAB/Simulink. Here with increase in levels the Harmonics can further be decreased and thus eliminating some of power quality issues of the Power system.

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